NUTRITIONAL COMPONENTS OF THE STANDING PLANKTON CROP IN MISSISSIPPI SOUND[1]

by

MOHAMMED SAEED MULKANA[2]
and
WALTER ABBOTT
Gulf Coast Research Laboratory
Ocean Springs, Mississippi 39564

ABSTRACT

A study on seasonal changes in the nutritional components of standing plankton biomass was made from 20 April 1965 to 6 September 1966. Plankton were separated into net plankton and nannoplankton fractions. Nannoplankton[3] standing biomass exceeded by 72 times that of net plankton.

Although protein and carbohydrate levels were higher in net plankton on a unit weight basis, total nutrients available from nannoplankton were substantially higher. Some seasonal trends were apparent as changes in the standing biomass in net plankton. Nannoplankton exhibited no seasonal trends. Lipid and caloric values of net plankton showed seasonal trends similar to those shown by dry weight.

INTRODUCTION

Early studies on marine plankton were directed primarily toward species composition, geographical distribution and seasonal successions. The importance of plankton to fisheries led to studies of plankton biomass, with considerable recent emphasis on plankton production as indicated by primary photosynthetic productivity. There are relatively few data, however, on specific nutritional components—carbohydrate, protein, and lipid—available from plankton and on quantitative seasonal changes in these components. Furthermore, although nannoplankton comprises the major fraction of the total plankton and exceeds the net plankton manyfold (Banse 1964, Pomeroy and Johannes 1966), those nutritional component data available relate only to net plankton.

[1] This work was supported in part by National Science Foundation Grant No. BG–3452, and is extracted from a Ph.D. Thesis submitted to Department of Zoology, Mississippi State University.

[2] Jackson County Campus, Miss. Gulf Coast Jr. College, Gautier, Mississippi 39553.

[3] It should be noted that the authors did not separate the nannoplankton from what has been called the nannodetritus and both components are included in the word nannoplankton, as used in this paper. Ed.

Mississippi Sound is regarded as a highly productive body of water (Gunter 1962, 1963, Christmas, Gunter, and Musgrave 1966) because of the influence of nutrient rich waters from Mississippi River (Riley 1937). This report is concerned with measurements of net plankton and nannoplankton dry weight, protein, and carbohydrate, and with lipid and caloric content of net plankton during a yearly cycle in Mississippi Sound.

MATERIALS AND METHODS

From April 20, 1965 to September 6, 1966, plankton was collected as near monthly as logistics and weather permitted from 6 sampling stations along two transects across Mississippi Sound—from Marsh Point to Horn Island (Fig. 1) and from Ship Island to Biloxi Beach (Fig. 1). The order of running the transects was systematically reversed from cruise to cruise to avoid sampling bias, but on each cruise one transect was worked by day and the other by night.

Composite net plankton samples were taken by pumping water from surface, mid-depth, and near bottom into a No. 20 plankton net

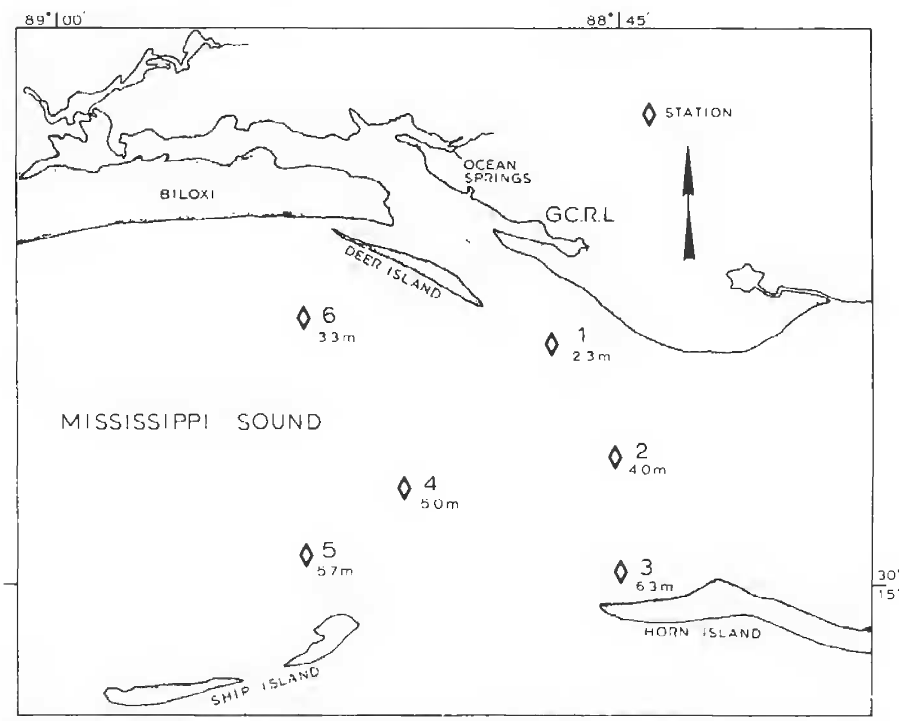

Figure 1. Map of Mississippi Sound showing sampling stations and depths. GCRL represents the site of the Gulf Coast Research Laboratory.

(76 μ mesh size) submerged in a water-filled container. The water was pumped at the rate of 190–240 liters/min. for 30 min. with a pre-calibrated pump. Leong (1967) has discussed plankton sampling by pumping in oceanographic situations. Our conditions were less severe because we used 5 cm pump instead of 1.27 pump and pumped water from a maximum depth of 8 meters rather than from 120 meters. As a result there should be less churning effect and less fragmentation of the planktonic organisms. A 19–liter aliquot of net filtrate was taken at each station as a nannoplankton sample. Both this aliquot and the net plankton sample were kept chilled by ice until return to the laboratory.

The nannoplankton samples were flocculated with potassium alum ($KAl(SO_4)_2$) to precipitate all suspended matter, plankton centrifuges having proved unsatisfactory for this purpose. The flocs were dissolved with just sufficient 3N hydrochloric acid and centrifuged at 1500 RPM for 15 minutes. Both net and nannoplankton concentrates were freed from water and salt by filtration on 0.8 μ Millipore type AA filters with a rapid wash with isotonic ammonium formate (Parsons, Stephens and Strickland 1961). Humphrey and Wootton (1966) have shown by pigment studies with *Gymnodinium, Nannochloris,* and sea water samples that delicate, small phytoplankton are retained as well by this Millipore filter as by those of lesser pore size. Samples were dried to constant weight at 105° C (Curl 1962) against a Millipore filter blank, scraped from the filter, and homogenized by grinding.

For measurement of protein content, portions of plankton homogenates, and albumin, used as standard, were hydrolyzed in a sealed vial with 6N HCl for 12 hours at 120° C (Welcher 1963). Hydrolysates were filtered, dried on a steam bath, and diluted to a standard volume. Amino acid content of plankton fractions and albumin hydrolysates was determined colorimetrically as leucine equivalents using a modification of the ninhydrin technique of Landua and Awapara (1949). The albumin equivalent of leucine, determined experimentally, was 6.97 μmol leucine/mg albumin.

Plankton carbohydrates were determined by hydrolyzing portions of homogenates, and oyster glycogen, used as standard, with 3N HCl for 1½ hours at 95° C. Hydrolysates were dried and glucose content was determined colorimetrically by the method of Folin and Wu (Department of the Army 1951).

Nannoplankton samples were too small for routine lipid analysis. Lipid from net plankton was extracted with chloroform–methanol–water (2:2:1) in a screw-capped Waring blender jar (Bligh and Dyer 1959). The homogenates were filtered and allowed to stand in separatory funnels with Teflon stopcocks until phases separated. The chloroform layer was removed, washed with chloroform–methanol–water

(3:48:47) (Folch, Lees and Stanley 1957), and dried with infrared lamp. Total lipid in the aliquots was determined spectrophotometrically by the method of Snyder and Stephens (1959) using triolein as standard.

Caloric measurements on net plankton were made according to Parr Manual No. 122 (1951) in a Parr Peroxide Bomb Calorimeter, Model 1401. Dried net plankton samples were ground to pass a 60 mesh screen. Particle size is important, because combustion reactions occur in a few seconds and large particles, if present, may not burn completely. Benzoic acid was used as combustion aid.

Ash content of plankton samples was determined by hot nitric acid digestion of the dried homogenate followed by ignition to constant weight in a muffle furnace at 550° C.

Salinity and temperature were determined *in situ* at each station by means of a Beckman Induction Salinometer. Figure 2 shows mean surface water temperatures during the course of this study.

All data for biomass, nutrients, and caloric values have been computed for a water column of 1 sq m area.

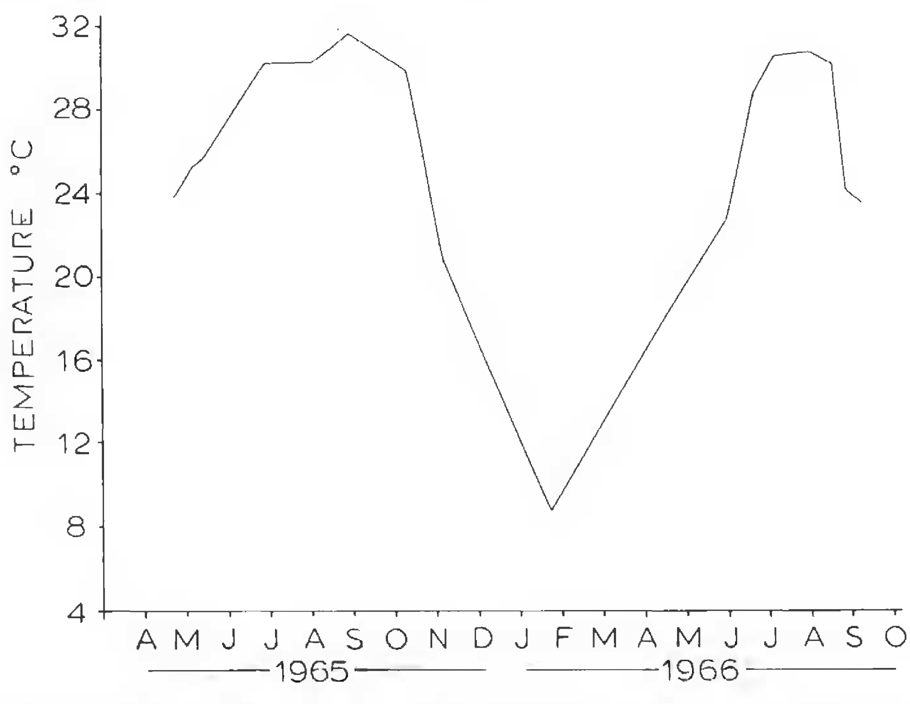

Figure 2. Mean surface temperature at six sampling stations from 20 April 1965 to 6 September 1966.

RESULTS

Dry Weight: The net plankton dry weight values of 637 mg/sq m and 452 mg/sq m (Fig. 3, Table 1) observed in April and May 1965,

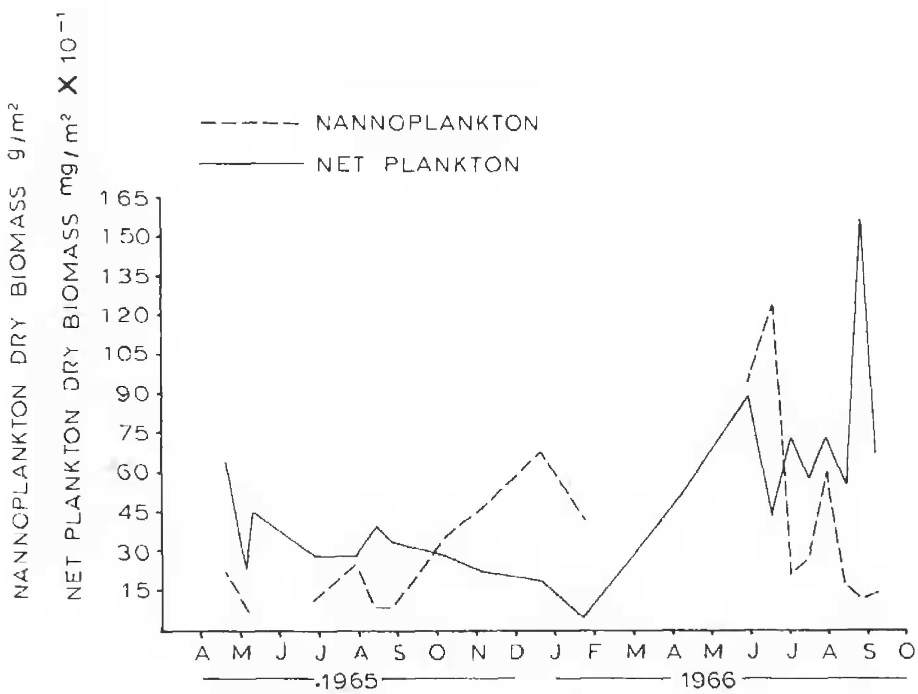

Figure 3. Seasonal variation in mean values of dry biomass of net plankton and nannoplankton.

respectively, derived from a plankton increase because of vernal warming in Mississippi Sound (Thomas and Simmons 1960). The peak of 401 mg/sq m in August 1965, appeared to be due to increased herbivore populations. The magnitude of spring and summer peaks in 1966 was considerably higher than peaks in 1965. Deevey (1960) indicated that the zooplankton seasonal cycle in nearshore waters may be extremely variable from one year to the next. On several occasions in summer 1966 concentrations of a blue-green alga, *Trichodesmium* sp., were observed in surface waters. The algal abundance would contribute markedly to the upswing in standing biomass. Beginning in late summer 1965, a gradual decrease in standing dry weight ensued, with a minimum of 43 mg/sq m in January 1966. A similar trend was noted again in 1966, when average values showed a sharp decline during September, decreasing from 1560 mg/sq m to 681 mg/sq m (Table 1).

Table 1.

Summary of Mean Values for Dry Weight, Nutrients, Ash Content and Caloric Values in the Standing Biomass of Net Plankton. Means have been Computed from Results at Six Stations

Date	Dry Weight mg/sq m	Protein mg/sq m albumin	Carbohydrate mg/sq m glycogen	Lipid mg/sq m triolein	Ash mg/sq m	Total nutrient and ash as per-cent dry weight	kcal/ sq m
1965							
20 April	637	158	29	15	217	65	1.7
4 May	228	62	9	8	113	84	0.5
11 May	452	100	7	15	230	78	0.9
25 June	284	96	9	11	147	92	0.6
31 July	282	63	6	8	171	88	1.1
14 August	401	104	7	11	208	82	0.8
26 August	337	66	6	16	130	65	1.1
7 October	285	73	4	4	166	87	0.6
4 November	225	47	4	5	129	82	0.5
20 December	194	17	10	1	110	71	
1966							
23 January	43	15	1	1	22	90	
8 April	508	92	24	9	175	59	1.3
28 May	898	172	15	11	463	74	2.2
17 June	444	76	7	16	219	72	1.0
1 July	739	217	37	12	389	88	1.9
15 July	581	197	34	16	276	90	1.1
19 July	740	271	20	19	402	96	1.8
13 August	566	185	32	14	292	92	1.2
26 August	1560	470	32	48	778	85	3.3
6 September	681	235	16	34	310	87	1.7
Grand Mean	504	136	15	14	247	81	1.3

The nannoplankton dry weight exceeded the net plankton dry weight manyfold, and showed a mean ratio to net plankton of 140:1, with the maximum in winter and the minimum in summer (Tables 1, 2 and 3). Yentsch and Ryther (1959), on the basis of chlorophyll *a* values, and Johannes (1964), on the basis of dry biomass, pointed out that nannoplankton comprised the major fraction of the total plankton.

The nannoplankton crop showed no definite seasonal trend, biomass peaks at various stations appearing in spring, fall, midsummer, and midwinter (Fig. 3). Mean dry weight values ranged from 7.50 g/sq m to 21.8 g/sq m in spring and from 7.9 g/sq m to 25.4 g/sq m

Table 2.

Summary of Mean Values for Dry Weight and Nutrients in Nannoplankton. Means have been Computed from Results at Six Stations

Date	Dry Weight g/sq m	Protein g/sq m albumin	Carbohydrates g/sq m glycogen
1965			
20 April	21.8	1.4	0.5
4 May	7.5	0.8	0.1
25 June	10.9	1.3	0.5
31 July	25.4	1.8	0.6
14 August	8.0	0.9	0.3
26 August	7.9	0.5	0.3
7 October	37.0	1.6	1.1
4 November	46.7	1.3	1.4
20 December	67.6	1.1	0.5
1966			
23 January	42.8	1.0	2.3
28 May	95.2	2.7	0.5
17 June	123.5	6.3	6.0
1 July	22.8	2.3	1.4
15 July	28.5	1.7	1.0
29 July	61.2	3.5	1.3
13 August	17.2	3.2	0.7
26 August	12.4	2.5	0.4
6 September	14.8	2.9	0.6
Grand Mean	36.2	2.0	1.9

Table 3.

Seasonal Variation in Nannoplankton-to-Net Plankton Ratios for Dry Weight, Proteins, and Carbohydrates

Date	Dry Weight nanno/net	Proteins nanno/net	Carbohydrate nanno/net
1965			
20 April	34	9	17
4 May	33	13	17
25 June	38	13	62
31 July	90	29	100
14 August	20	9	48
26 August	24	7	57
7 October	130	22	278
4 November	208	27	310
20 December	348	64	55
1966			
23 January	996	65	2086
28 May	106	16	34
17 June	278	82	903
1 July	31	11	39
15 July	49	9	87
29 July	83	13	65
13 August	30	17	22
26 August	8	5	14
6 September	22	12	37

in summer 1965 (Table 3). An average nannoplankton rise was noticed starting in fall and reaching a maximum, 67.6 g/sq m, in December 1965. The nannoplankton–to–net plankton dry weight ratio was 996:1 in January 1966 and 8:1 in late August 1966, the highest and lowest for the entire study period (Table 3). Such an extreme difference in ratio probably resulted from low production of net plankton and little or no spawning and breeding activity of herbivores at a time when production at the nannoplankton level was high. Both fractions maintained higher average standing dry weights in summer than in winter, with a differential, larger increase in net plankton.

Protein: Protein comprised the largest component of net plankton nutrients. The dry weight–to–protein ratio was 3.7:1, equivalent to 27% protein. Parsons, Stephens and Strickland (1961), Raymont

(1963), and Blazka (1966) have shown considerably higher relative protein levels in net plankton, apparently because their samples were not contaminated by the large amounts of detritus, clay, and silt usually present in collections from Mississippi Sound. The high ash content in our net plankton samples should account for the low relative protein level.

Mean net plankton protein for all samples was 136 mg/sq m. The level varied from 62 mg/sq m to 158 mg/sq m between April and August 1965 (Fig. 4). With the seasonal temperature decline, protein

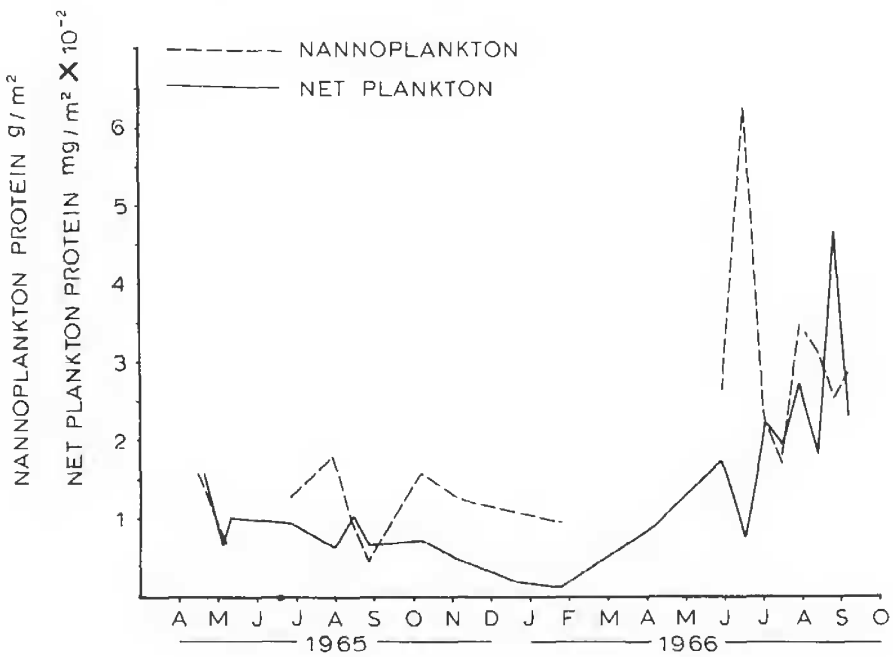

Figure 4. Seasonal variation in mean values of protein of net plankton and nannoplankton.

values decreased to 15 mg/sq m in January 1966. As temperatures rose again with the onset of spring, net plankton protein values again increased, reaching 470 mg/sq m in August 1966. The summer maximum for 1966 was considerably higher than the summer values for 1965 and followed the same trend as net plankton dry weight.

The dry weight-to-protein ratio in nannoplankton was 18:1, equivalent to 5.5% protein. Similar low levels of protein in smaller plankton organisms have been reported by Blazka (1966), Raymont (1963), and Parsons, Stephens and Strickland (1961). This supports the concept that nannoplankton are mainly composed of photosynthesising elements and, hence, are mainly carbohydrate, not protein (Fig. 5). Nannoplankton protein ranged from 0.5 g/sq m to 1.8 g/sq m during the April–December 1965 period, with maximum and minimum occurring in the summer (Table 2). Data for 1966 indicated greater variability in available protein. Values fluctuated between 1.0 g/sq m and 6.3 g/sq m, with marked variations during the summer. Although the protein level in nannoplankton was extremely low, the nannoplankton–to–net plankton mean protein ratio on a water column basis was 24:1 (Table 3).

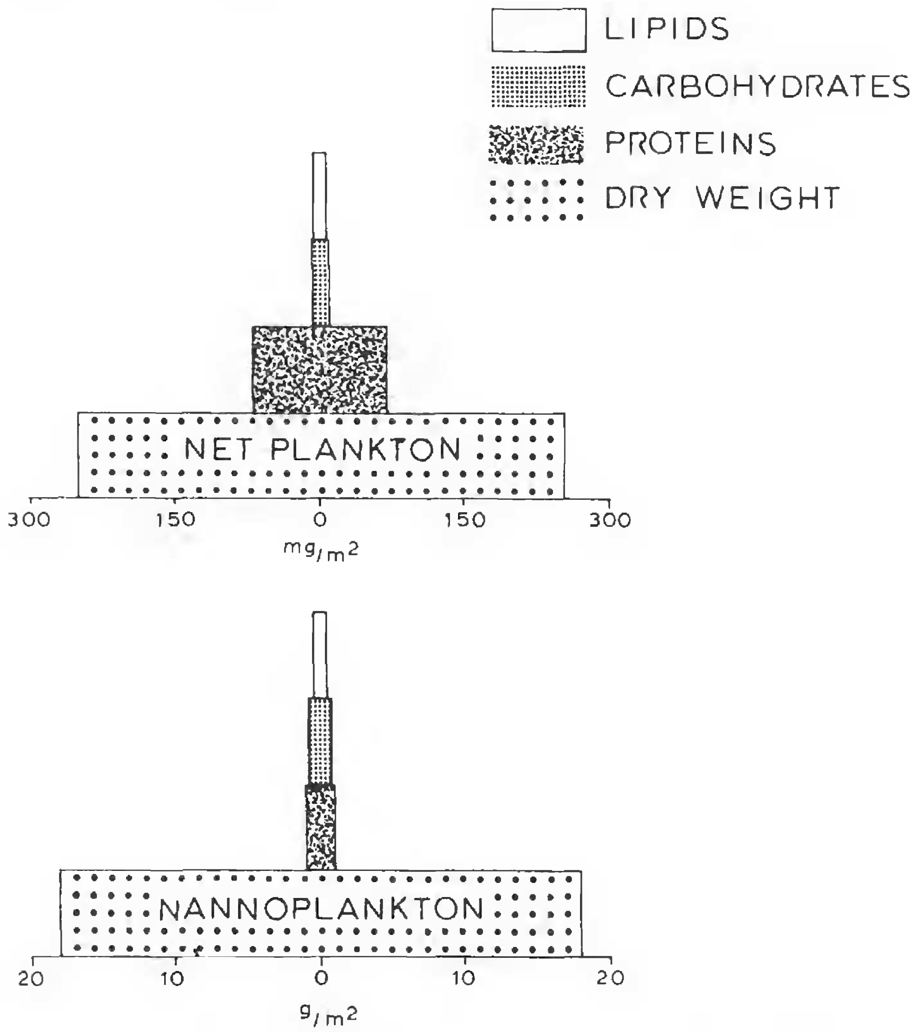

Figure 5. Average nutrient composition and dry weight of Mississippi Sound plankton.

Carbohydrate: Carbohydrate composed 3% of the dry net plankton sample, giving a carbohydrate-to-protein ratio of 1:9. Various biochemical studies on plankton agree that carbohydrate level in net plankton is relatively low and protein makes up most of the nutrient component (Raymont and Conover 1961, Parsons, Stephens and Strickland 1961, Blazka 1966). Carbohydrate values for April 1965 and April 1966 were 29 mg/sq m and 24 mg/sq m, respectively (Table 1). From late spring to winter 1965, values remained at or below 10 mg/sq m with a minimum of 1 mg/sq m in January 1966 (Fig. 6).

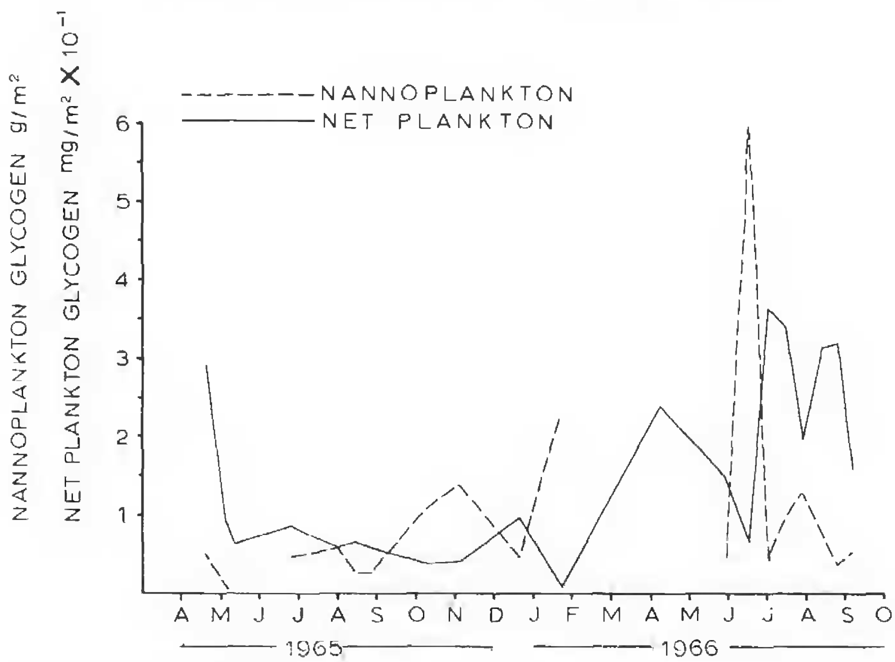

Figure 6. Seasonal variation in mean values of carbohydrate of net plankton and nannoplankton.

Nannoplankton mean carbohydrate content was 1.9 g/sq m, 5% of the dry weight, with a mean ratio of 1:1:18 for carbohydrate:protein:dry weight (Table 2). Carbohydrate and protein formed only about 10% of the dry weight, the low nutrient content in nannoplankton apparently resulting from large amounts of detritus and clay admixed with nannoplankton samples. Ash weight determinations on 15% of the samples gave values as high as 85% ash. Although nannoplankton showed a lower percentage nutrient content, on a unit area basis average carbohydrate level was a total of 235 times that of net plankton. Protein and carbohydrate maintained almost the same levels in the nannoplankton and showed similar seasonal fluctuations.

Lipid: The average net plankton lipid was 2.7% of the dry weight. The maximum, 16 mg/sq m, and minimum, 1 mg/sq m, values were observed in August and December, respectively, in 1965 (Fig. 7). In 1966, minimum, 1 mg/sq m, and maximum, 48 mg/sq m, occurred respectively, in January and August. From August 1965 onward, lipid values declined sharply to a minimum in winter and gradually increased with the onset of vernal conditions in 1966. The lipid content relative to the dry weight, during August lipid peaks, was 4.7% in 1965 and only 3% in 1966 when a considerably higher standing crop was noted (Table 1). Wimpenny (1938) reported similar results from the North Sea, and indicated that lipid content was lower when higher standing biomass was present. Fisher (1962) pointed out that size, spawning, maturity, and season affect lipid content of plankton, but he attributed the difference in lipid content to a differential in species composition from one year to the next. Lipid content in spring samples, which consisted predominantly of phytoplankton, was lower than in summer samples which included considerable zooplankton (Table 1). Blazka (1966) indicated that lipid content per unit biomass increases from algae to zooplankton in fresh water habitats. Possibly this is true in marine environments as well.

Nannoplankton samples were too small for routine determination of lipid content, but based upon a single cruise, when 18 gallons of net filtrate from each of the six stations were processed, lipid content was found to be 1.2% of nannoplankton dry weight.

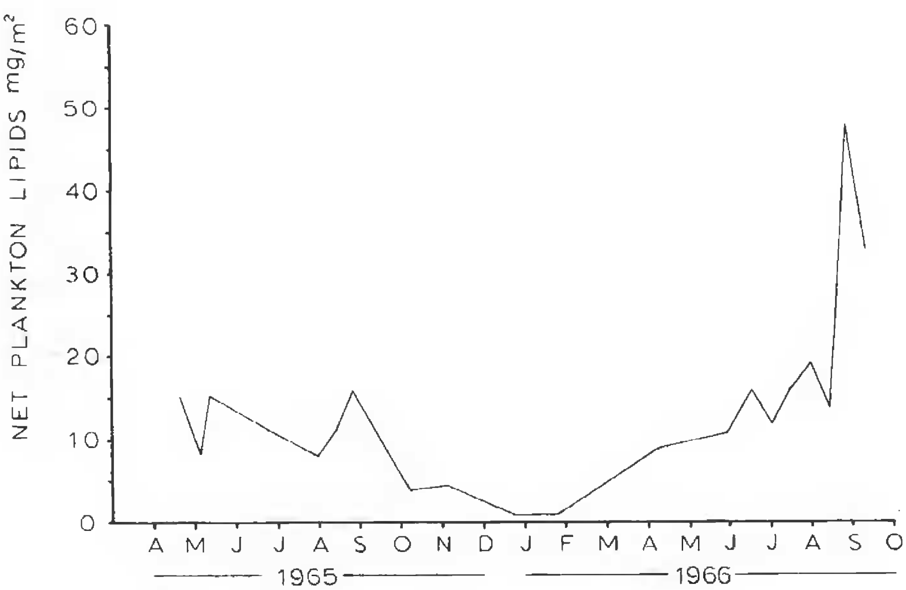

Figure 7. Seasonal variation in mean value of lipids of net plankton.

Figure 4 summarizes dry weight and nutrient composition data for net plankton and nannoplankton.

Caloric values and ash content: With one exception, net plankton caloric values, averaged for six stations on each date, fell within the range 3.6–5.4 kcal/ash-free g (Fig. 8). This is a remarkable consis-

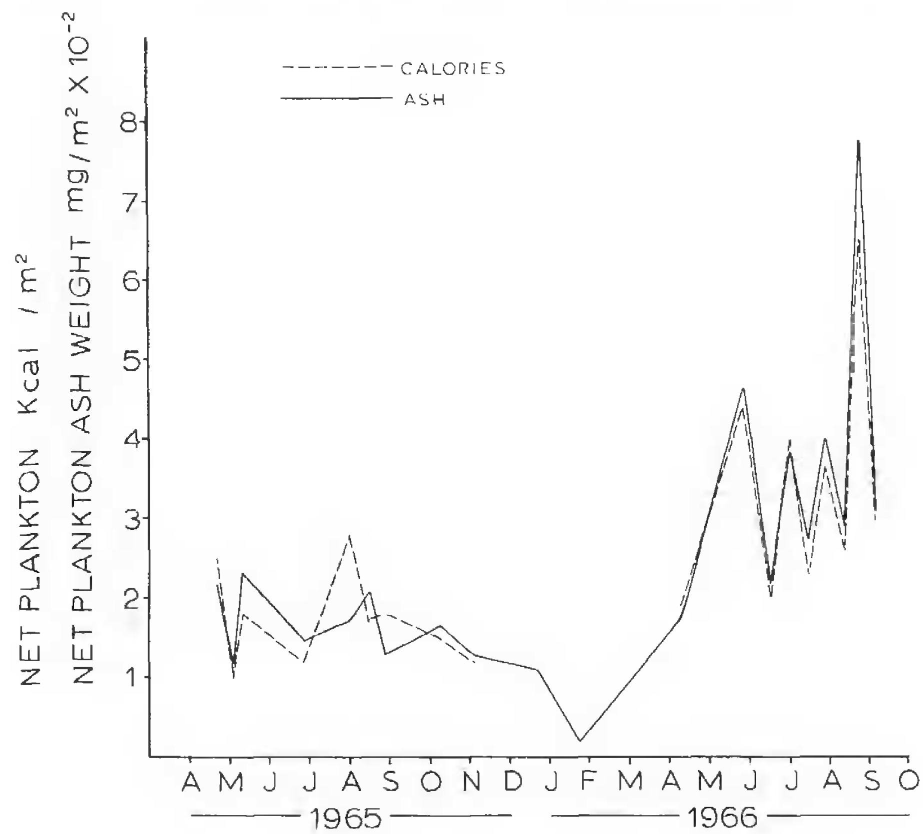

Figure 8. Seasonal variation in mean caloric values and ash weights of net plankton.

tency, considering that net plankton dry weights in the same sample series varied from 225 mg/sq m to 1560 mg/sq m. The mean value for the entire series was 4.85 kcal/ash-free g. Richman (1958) and Golley (1961) reported similar values for *Daphnia*, but caloric values obtained for Copepoda and Cladocera by Sitaramiah (1967) were as high as 7.02 kcal/ash-free g. Paine (1964) indicated that higher values are usually found for eggs and resting stages, although well-fed zooplankton also show a high caloric content periodically. The extreme value found in the mixed net plankton samples in the present analyses was 9.9 kcal/ash-free g. This extremely high result derives from an anomalous datum from one station on one date, and may reflect a technical error.

The plankton samples yielded high ash contents throughout the period of study. Paine (1964) suggested that in organisms high in ash content, such as sponges and opisthobranchs, at least some low caloric estimates may result from difficulties in determining accurately the amount of noncombustible material present. Corrections for endothermic combustion reactions due to high ash content may be made as suggested by Paine (1966), but plankton samples may at times contain large amounts of low energy-yielding organic detritus, thus causing low estimates. The wet-ashing procedure employed in this investigation destroys carbonates and leads to low ash estimates, thus giving rise to slightly low results when caloric values per unit weight are computed on an ash-free basis.

Caloric content on a unit area basis followed a general trend similar to that shown by other parameters. Thus, the highest caloric value for 1965, 1.7 kcal/sq m on April 20, corresponded to the highest value for dry weight in 1965. In 1966, highest values for all parameters except carbohydrate corresponded to highest standing dry weight. Although caloric data for winter and early spring are not available, a trend towards decline in values was apparent after the peak in summer 1965. This may be associated with seasonal decrease in temperature. Vernal rise in caloric content was again noted in 1966, along with the rise in other parameters. The caloric value obtained in August 1966, 3.3 kcal/sq m, was the highest for the year. Other parameters in 1966 showed similar trends.

DISCUSSION

Nannoplankton, by definition, is that portion of the total plankton not obtained in tow-net collections. Since it is difficult to collect in quantity and even more difficult to study by classical, systematics–oriented methods, nannoplankton, historically, has been ignored to a large extent in favor of net plankton.

Nevertheless, various workers, approaching the assay of the total plankton from several standpoints, have all agreed that, at least in temperate and tropical waters, nannoplankton dominates the primary producer trophic level. Thus, Pomeroy and Johannes (1966) found that 94–99% of total plankton respiration resulted from organisms too small to be retained by a fine net; Banse (1964) estimated that nannoplankton made up more than half of the total plankton; and Yentsch and Ryther (1959) reported that, in Vineyard Sound, net plankton represented, in various samples, 2–47% of total plankton biomass. The latter authors also tabulated other earlier results, including a report by Riley from Tortugas that net plankton amounted to only one percent of total plankton.

The study described here relates to observations on the total plankton crop of Mississippi Sound. Turbulent conditions are the rule in this body as in other Gulf Coast estuaries and lagoons, because of shallow waters, extensive wind stirring, river discharge from the mainland, and tidal mixing from the Gulf of Mexico through various passes between barrier islands. As a result, clay particles and detritus stay in suspension and become admixed with plankton samples, thereby giving rise to high ash values. Further, limited data indicate that, probably because of fine clays, ash is differentially increased in the nannoplankton fraction.

Despite this, nannoplankton, on a unit-area, total–water–column basis shows a total organic content greater by orders of magnitude than net plankton organic content. Thus, for an 18–month period in 1965 and 1966, mean nutritional composition of net plankton was 136 mg/sq m protein, as albumin, 15 mg/sq m carbohydrate, as glycogen, and 14 mg/sq m lipid, as triolein. During the same period, nannoplankton samples from the same stations and times showed means of 2.0 g/sq m protein and 1.9 g/sq m carbohydrate. These values were associated with mean dry weights of 504 mg/sq m for net plankton and 36.2 g/sq m for nannoplankton, including ash contents of 49% for net plankton and, based on very limited samples, 65% for nannoplankton.

The net plankton nutritional values amount, on a dry weight basis, to 27% protein, 3% carbohydrate, and 3% lipid. These levels are considerably lower than published results based on clay-free samples or individual species (Parsons, Stephens and Strickland 1961, Linford 1965, Raymont and Linford 1966, Blazka 1966). For nannoplankton, comparable data are not at hand. However, it has been pointed out by Gunter (1938, 1941, 1967) that most abundant species of fishes on the northern Gulf Coast feed at the base of the food chain. These are the menhaden, *Brevoortia patronus* and *B. gunteri*, the anchovy, *Anchoa mitchilli*, and the mullet, *Mugil cephalus*. Quite probably a considerable portion of their food is nannoplankton but there are no good data, although Peck (1894) said that menhaden filtered out dinoflagellates and minute plankton. There seems to be little doubt that oysters and other pelecypods feed to a considerable extent on nannoplankton (Nelson 1925, 1947) and filter feeding smaller crustaceans may also be in part based on nannoplankton.

No geographically uniform seasonal trend was found for nannoplankton standing crop, although net plankton did exhibit such a trend, a result in accord with the findings of Yentsch and Ryther (1959). Unfortunately, no method was available for estimating the relative contribution of salt marsh detritus to the two plankton fractions. This detritus might either emphasize or mask a trend, since Odum and de la Cruz (1967) suggested that outpourings from Georgia salt marshes provided the major organic load in Georgia estuaries, and that the majority of this was "nanno detritus." Study on the yearly cycle of nannoplankton carbohydrate in Louisiana estuaries by Mulkana (1969), however, shows a normal seasonal trend associated with rise and decline of temperature.

Net plankton caloric values, on an ash-free weight basis, were consistent with various reported values in the literature. On the average, the caloric value of 1 g, ash-free, of net plankton was equivalent to 1.3 g glucose. On an area basis, caloric values were relatively steady. There was one extreme value of 3.3 kcal/sq m in August 1966, but the remainder fell in the range 0.5–2.2 kcal/sq m.

Nannoplankton samples were insufficient to permit caloric determinations, but should show larger values than net plankton per unit area consistent with the much larger standing crop of nannoplankton.

SUMMARY

1. On a unit area basis, mean nannoplankton dry weight was 72 times that of net plankton from April 1965 to September 1966 in Mississippi Sound.
2. The mean net plankton protein, carbohydrate and lipid were found to be 136 mg/sq m, 15 mg/sq m and 14 mg/sq m, respectively. The mean nannoplankton protein and carbohydrate were, respectively, 2.0 g/sq m and 1.9 g/sq m.
3. Mean levels of net plankton protein, carbohydrate and lipid were 27, 3, and 2.8%, respectively, of net plankton dry weight. In nannoplankton, protein and carbohydrate were 5.5 and 5%, respectively, relative to dry weight.
4. Although nutrient levels were higher in net plankton on unit weight basis, total nutrients available from nannoplankton were substantially higher. The mean nannoplankton–to–net plankton protein and carbohydrate ratios per unit water column were 24:1 and 235:1, respectively.
5. Some seasonal trends were apparent as changes in the standing biomass of net plankton, associated with temperature rhythm. Nannoplankton exhibited no definite seasonal trends. Present results suggest that factors other than temperature, such as grazing activity of herbivores and detritus influx, strongly influence nannoplankton dry weight.
6. Caloric values of net plankton showed seasonal trends similar to

those shown by dry weight. Average net plankton caloric value during the study period was 1.3 kcal/sq m.

LITERATURE CITED

Banse, K. 1964. On the vertical distribution of zooplankton in the sea. *In*: Progress in Oceanography. Ed. by M. Sears. Pergamon Press, New York, pp. 53–125.

Blazka, P. 1966. The ratio of crude protein, glycogen and fat in the individual steps of the production chain. *In*: Hydrobiological Studies. Ed. by J. Hrbacek. Academia Pub. House, Czechoslovac Acad. Sci., pp. 395–408.

Bligh, E. G., and W. J. Dyer. 1959. A rapid method of total lipid extraction and purification. Can. J. Biochem. Physiol. 37, pp. 911–17.

Christmas, J. Y., G. Gunter and P. Musgrave. 1966. Studies on annual abundance of postlarval penaeid shrimp in the estuarine waters of Mississippi, as related to subsequent commercial catches. Gulf Res. Rep. 2:177–212.

Curl, H. Jr. 1962. Standing crops of carbon, nitrogen, and phosphorus and transfer between trophic levels in continental shelf waters south of New York. Rapp. P.–v. Reun Cons. perm. int. Explor. Mer 153, pp. 183–89.

Department of the Army. 1951. Methods for Medical Laboratory Technicians. Manual No. TM8–227. Superintendent of Documents, U. S. Printing Office, Washington 25, D. C.

Deevey, G. B. 1960. The zooplankton of the surface waters of the Delaware Bay region. Bull. Bingham oceanogr. Coll. 17, pp. 5–53.

Fisher, L. R. 1962. The total lipid material in some species of marine zooplankton. Rapp. P.–v. Reun Cons. perm. int. Explor. Mer 153, pp. 129–35.

Folch, J., M. Lees and G. H. Sloane Stanley. 1957. A simple method for the isolation and purification of total lipids from animal tissues. J. Biol. Chem. 226, pp. 497–509.

Golley, F. B. 1961. Energy values of ecological materials. Ecology 42, pp. 581–83.

Gunter, G. 1938. The relative numbers of species of marine fish on the Louisiana coast. The American Naturalist, 72:77–83.

————. 1941. The relative number of shallow fishes of the northern Gulf of Mexico, with some records of rare fishes from the Texas coast. The American Midland Naturalist, 26(1):194–200.

————. 1962. Shrimp landings and production of the State of Texas for the period 1956–1959, with a comparison with other Gulf states. Publ. Inst. Marine Sci., Univ. Texas. 8:216–26.

————. 1963. The fertile fisheries crescent. J. Miss. Acad. Sci. 9:286–290.

————. 1967. Some relationships of estuaries to the fisheries of the Gulf of Mexico. Part IX Fisheries, pp. 621–638, Estuaries, George H. Lauff, Ed., Publication No. 83, Amer. Assoc. Advan. Sci., Washington, D. C. 1967.

Humphrey, G. F., and M. Wootton. 1966. Comparison of the techniques used in the determination of phytoplankton pigments. Monographs on Oceanographic Methodology, UNESCO 1, pp. 37–63.

Johannes, R. E. 1964. Phosphorus excretion and body size in marine animals: microzooplankton and nutrient regeneration. Science, N. Y. 146, 923–24.

Landua, A. J., and J. Awapara. 1949. Use of modified ninhydrin reagent in quantitative determination of amino acids by paper chromatography. Science, N. Y. 109, 385.

Leong, R. 1967. Evaluation of a pump and reeled hose system for studying the vertical distribution of small plankon. U. S. Fish Wildl. Serv. Spec. Rept. Fisheries No. 545.

Linford, E. 1965. Biochemical studies on marine zooplankton. II. Variations in the lipid content of some Mysidacea. J. Cons. perm. int. Explor. Mer 30,:16–27.

Mulkana, M. S. 1969. An annual nannoplankton carbohydrate cycle in Bartaria Bay, Louisiana, and its adjacent areas. J. La. Acad. Sci. 32:62–8.

Nelson, T. C. 1925. The nannoplankton as source of the oyster's food. Report: Agricultural College Experimental Station, Brunswick, New Jersey, 243.

________. 1947. Some contribution from the land in determining conditions of the life in the sea. Ecol. Monogr., 17:337–46.

Odum, E. P., and A. de la Cruz. 1967. Particulate organic detritus in a Georgia salt marsh-estuarine ecosystem. AAAS Publ. 83, 383–8.

Paine, R. T. 1964. Ash and caloric determinations of sponge and opisthobranch tissues. Ecology 45, 384–7.

________. 1966. Endothermy in bomb calorimetry. Limnol. Oceanogr. 11, 126–9.

Parsons, T. R., K. Stephens and J. D. Strickland. 1961. On the chemical composition of eleven species of marine phytoplankters. J. Fish. Res. Bd. Can. 18, 1002–15.

Peck, J. I. 1894. On the food of the menhaden. Bull. U. S. Fish Commn. (1893) XIII, 113–126, Pl. 1–8.

Pomeroy, L. R., and R. E. Johannes. 1966. Total plankton respiration. Deep Sea Res. 13, 971–3.

Raymont, J. E. G. 1963. Plankton and Productivity in the Oceans. The Macmillan Company, New York.

________, and R. J. Conover. 1961. Further investigation on the carbohydrate content of marine zooplankton. Limnol. Oceanogr. 6, 154–64.

________, and E. Linford. 1966. A note on the biochemical composition of some Mediterranean zooplankton. Int. Revue ges. Hydrobiol. 51, 485–8.

Richman, S. 1958. The transformation of energy by Daphnia pulex. Ecol. Monogr. 28, 273–91.

Riley, G. A. 1937. The significance of the Mississippi River drainage for biological conditions in the northern Gulf of Mexico. J. Marine Res. 1:60–74.

Sitaramiah, P. 1967. Water, nitrogen and calorific values of freshwater organisms. J. Cons. perm. int. Explor. Mer 31, 27–30.

Synder, F., and N. Stephens. 1959. A simplified spectrophotometric determination of ester groups in lipids. Biochem. biophys. Acta 34, 244–45.

Thomas, W. H., and E. G. Simmons. 1960. Phytoplankton production in the Mississippi Delta. *In*: Recent Sediments, Northwestern Gulf of Mexico. Symposium, Amer. Petrol. Inst. Project 51, 1951–8.

Welcher, F. J. 1963. Standard methods of chemical analysis. Part A. 2, 920–2.

Wimpenny, R. S. 1938. A routine method for the estimation of fat in plankton and its application to herring tissues. J. Cons. perm. int. Explor. Mer 13, 338–48.

Yentsch, C. S., and J. H. Ryther. 1959. Relative significance of the net phytoplankton and nannoplankton in the waters of Vineyard Sound. J. Cons. perm. int. Explor. Mer 24, 232–8.